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Background Noise in Underwater Acoustic Listening Systems.

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for Technology

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20

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Naval Underwater Systems Center
Newport, Rhode Island • New London, Connecticut

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PREFACE

This document contains a paper presented during a symposium on *Sound Propagation and Underwater Systems* at Imperial College on 10 and 11 April 1978. The meeting was sponsored by the Institute of Acoustics, Underwater Acoustics Group.

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12

BACKGROUND NOISE IN UNDERWATER ACOUSTIC LISTENING SYSTEMS

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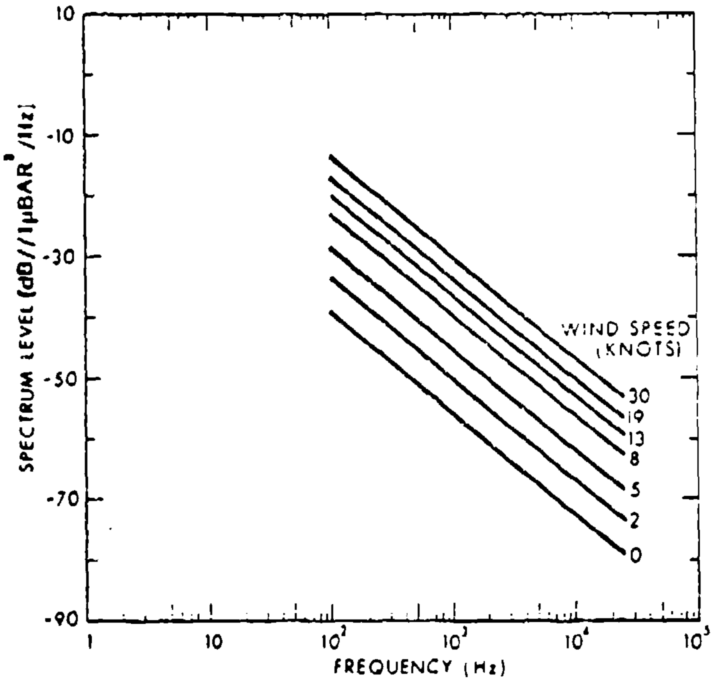
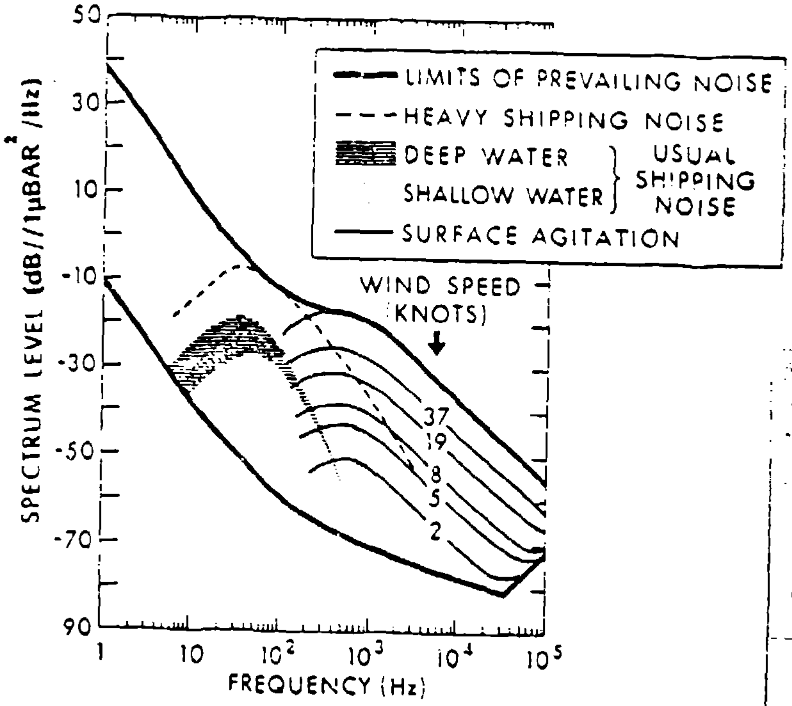
In the last few years it has been shown that under most circumstances there are two primary sources of ambient noise in the frequency range from 10 to 10,000 Hz. Their relative importance varies from situation to situation, and under some conditions, such as heavy rain or high biological-noise levels, additional sources are important. However, in all cases, the two primary sources must be considered.

One of these sources is surface agitation. It is highly wind-dependent, and the noise that it generates arrives at our systems from vertical and nearly-vertical angles. The other source is distant shipping. Shipping noise is not wind-dependent and arrives at listening systems from nearly-horizontal angles. If one neglects nearby shipping, then this noise is characteristically lower in frequency than surface noise and propagates for long distances.

The information presented here will relate to knowledge of ambient noise consisting of contributions only from the two primary sources--surface agitation and distant shipping. We shall consider first the reliability with which ambient-noise levels can be predicted and then the important characteristics of the noise itself.

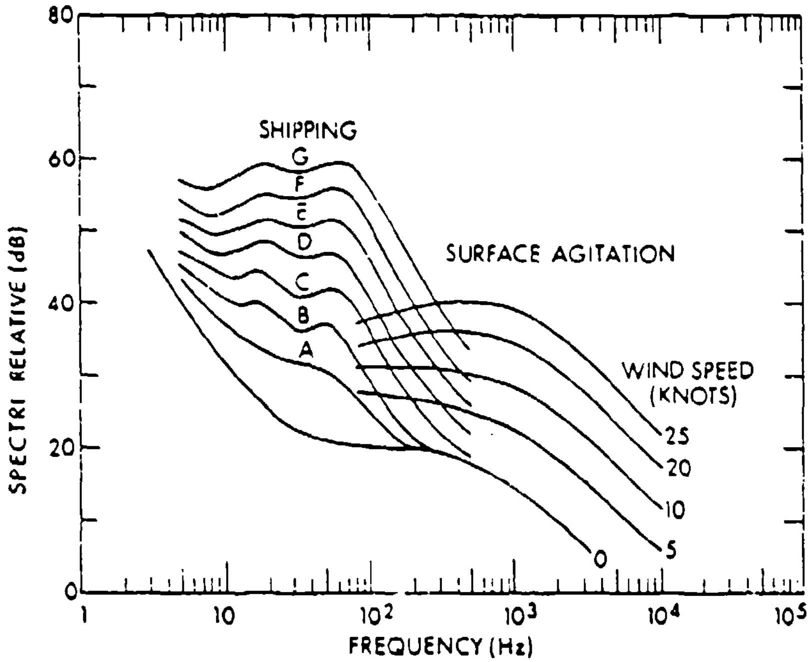


One can confidently predict future ambient-noise levels in an ocean area only after extensive measurements in that area. However, this is seldom the case; predictions are almost always made on the basis of data averaged over long periods of time and over large geographical areas. Knudsen, et al. were the first to publish such averages These very simple linear relationships show the change in ambient-noise spectrum levels with respect to wind speed. Although most of the averaged data were derived from shallow-water measurements, their values above 1000 Hz are in good agreement with modern studies. Below 1000 Hz, their values are higher than any of the recent studies.

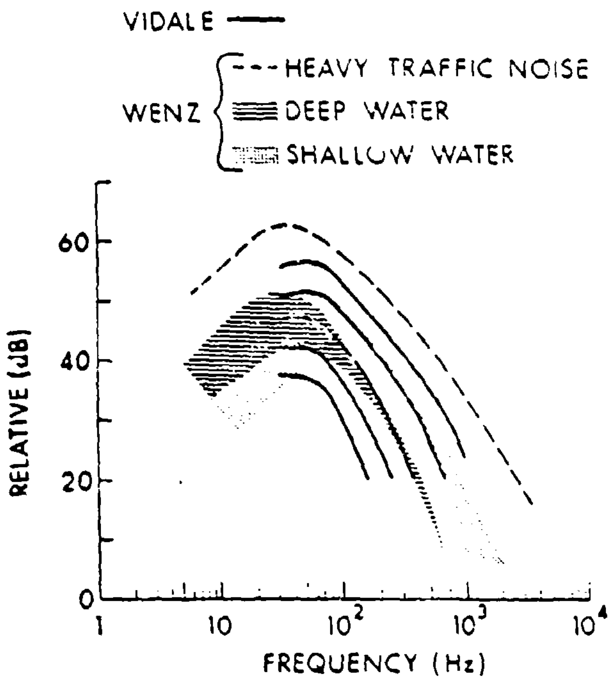


Significant contributions were made in 1962 by Wenz and by A. D. Little, Inc. Wenz included discussions of many sources and predictions of their contribution to ambient noise. The primary sources (surface agitation and distant shipping) are shown here, along with the general limits of prevailing noise. Noise from distant shipping is limited to frequencies from about 10 to 1000 Hz and is shown for shallow water (dotted area), for deep water (lined area), and for unusually heavy traffic conditions (dashed line). Noise from surface agitation is found at frequencies from about 100 to at least, 10,000 Hz. Levels for various wind speeds are shown by the solid lines with the appropriate wind speeds indicated. The heavy lines indicate the overall limits for all sources under a wide variety of conditions.

In addition to this information on the primary sources, the data supplied by Wenz are an excellent reference for information on the nature of numerous other sources and on their contributions to observed ambient noise.



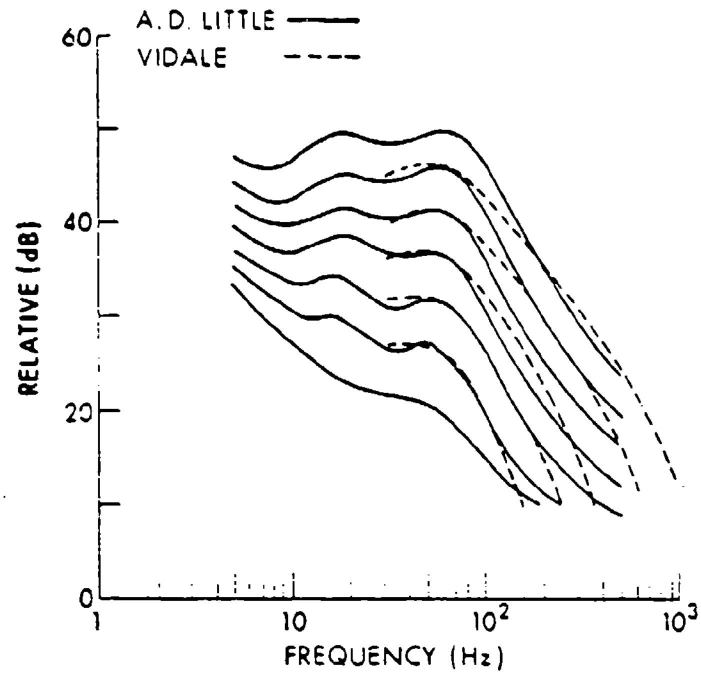
The A. D. Little work included only ship traffic and surface agitation. These are the predicted levels. An index is provided for 15 areas to enable selecting the appropriate shipping curve, A through G. Although the indexed areas provide more details about distant shipping noise than did Wenz, the areas are limited to those near the east and west coasts of the United States, the Caribbean, the Bering Straits, and New Zealand.



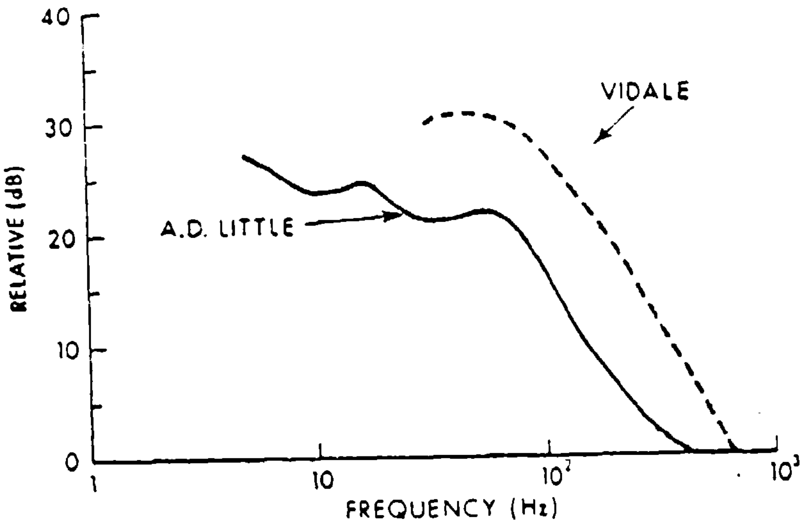
A recent study of this type was made by Vidale and Houston. They determined average levels for ship-generated noise in many more ocean areas than A. D. Little and, also, predicted mean spectrum levels for wide geographical areas, as well as the traditional spectrum levels as a function of wind speed. Since their work is based on more data than the studies of Wenz or A. D. Little, and since it is more comprehensive, most of the analysis that follows will be concerned with the accuracy of their findings.

All three predictions for ambient noise from surface agitation are in good agreement. For ship traffic, however, there are signficant differences among all three. Vidale's curves have about the same shape as those by Wenz, but those by A. D. Little are different; that is, the range of values does not agree with those by Wenz or Vidale.

Here we see the similarity in the shape of the curves by Vidale and Wenz, but note that the ranges of the levels do not agree. Also, Vidale does not find the same relationship between levels in shallow water and in deep water.

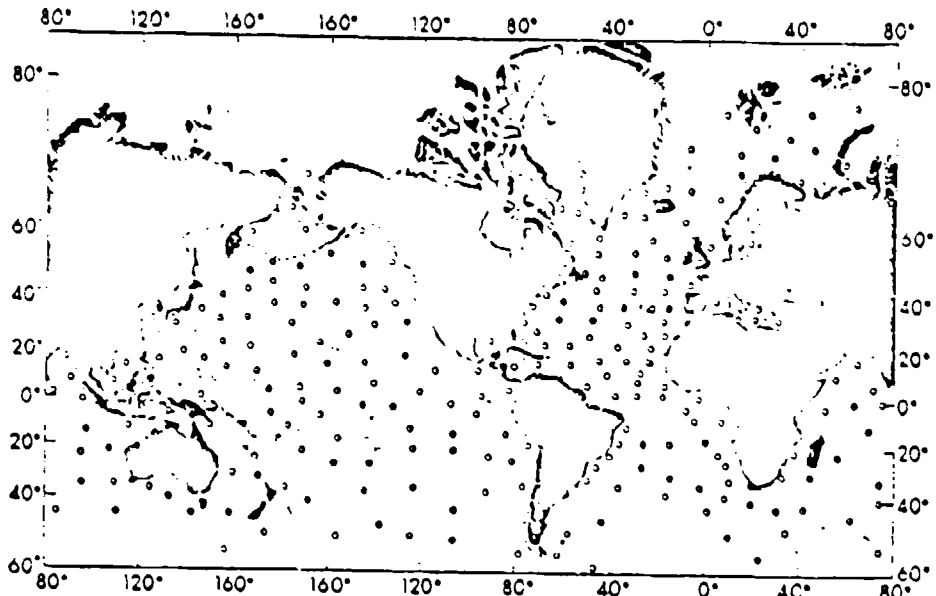


The different spectrum shapes found by Vidale and A. D. Little are illustrated here. There are 5 dB differences in levels at some frequencies for curves that are the same at other frequencies.



For more detailed comparisons, graphs were made of the noise predictions by A. D. Little for shipping and then those by Vidale for the same areas were superimposed. These results are typical of the predictions. The difference between the data by Vidale and A. D. Little at around 80 Hz (the topmost portion) ranged from zero to 14 dB, as shown by the shaded area. Vidale's were always higher.

There is no explanation for this marked difference, except that the additional data for the later study averaged out to higher levels. Such disparities are frequently observed in attempts to predict ambient-noise levels. Not enough is yet understood about ambient noise to account for the variations. When published the curves by A. D. Little were the best available estimates. Now the best estimates are as much as 14 dB higher.



A SPECTRUM LEVEL IS GIVEN FOR EACH DOT

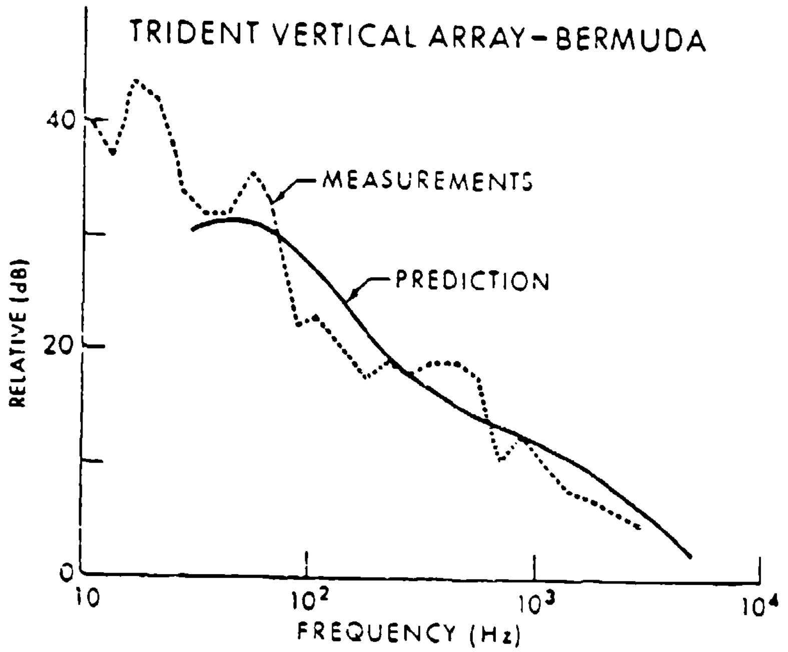
The new feature in the report by Vidale is the prediction of mean spectrum levels as a function of frequency, month, and geographical location. A map, such as this, is provided for the months of January, April, July, and October for the frequencies of 500, 1000, 200, and 5000 Hz. Thus there is available a total of 16 maps of the world like this one; that is, for each of the four months there are four maps corresponding to the four frequencies. A spectrum level is available for each black dot on the map.

These mean spectrum levels were derived from wind-speed data published by the U. S. Navy. The relationship between ambient noise and wind speed, discussed earlier, was used to compute the averages. Note that they are the average levels for the month. The ambient noise will vary with the weather, as shown previously in its relationship to wind speed.

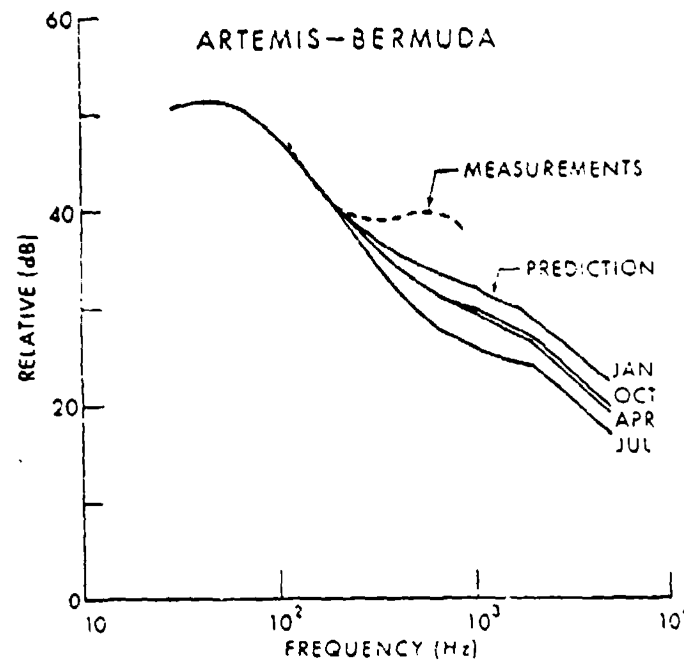
The prediction of mean spectrum levels, heretofore neglected, is a significant contribution. For many operations-analysis and performance-prediction situations, the expected mean ambient-noise level and the expected variation about the mean should be of concern. These factors determine the percentage of time that detection will be possible under noise-limited conditions. The dependence on wind speed gives additional information about the limitations of weather conditions, but it is not relevant to many planning situations.

Of the three studies discussed for predicting ambient noise, the one by Vidale is obviously the most specific in predicting the levels where wind and ship traffic are the primary sources. The one by Wenz would be useful if other sources of ambient noise are important.

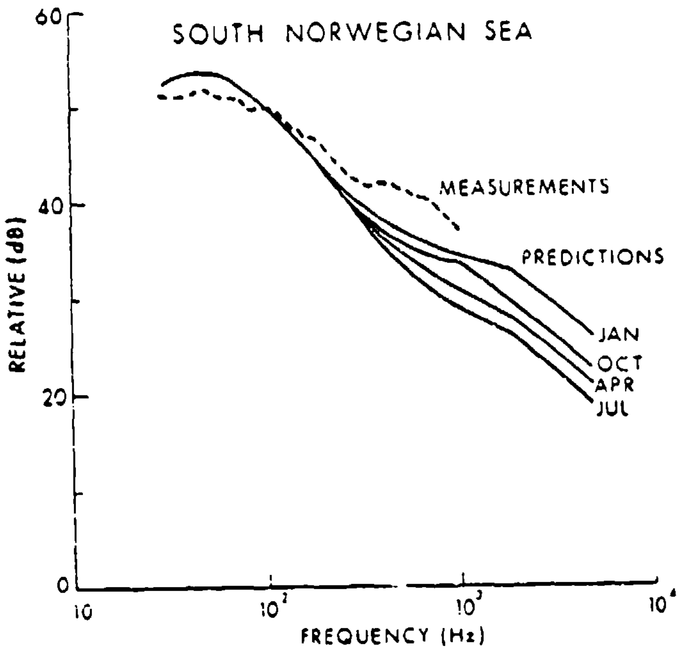
How well do these predictions match specific measurements? Vidale compared his world-wide predictions of mean spectrum level at 100 Hz with 147 measurements from various sources; he found that 97 percent agreed within 10 dB, 83 percent within 5 dB, and 57 percent within 3 dB.



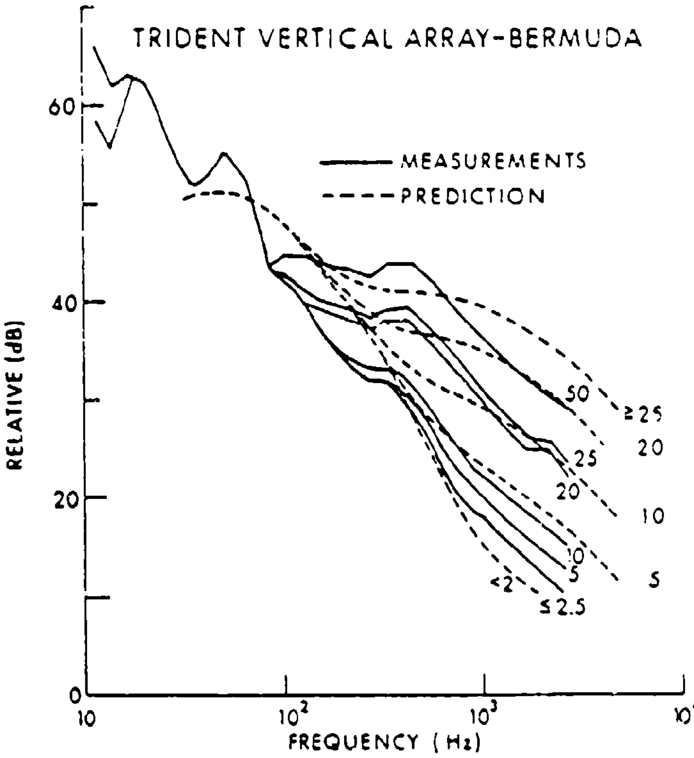
For additional comparisons, the mean spectrum levels measured by Perrone near Bermuda during the month of January and compared them with predictions by Vidale for the same area and month. In only one place is the difference between predictions and measured values greater than 4 dB. That is at 89 Hz.



The mean spectrum levels are determined near Bermuda with the ARTEMIS array. The mean for a two-year period is shown here. Above 200 Hz, it is as much as 8 dB higher than the prediction.

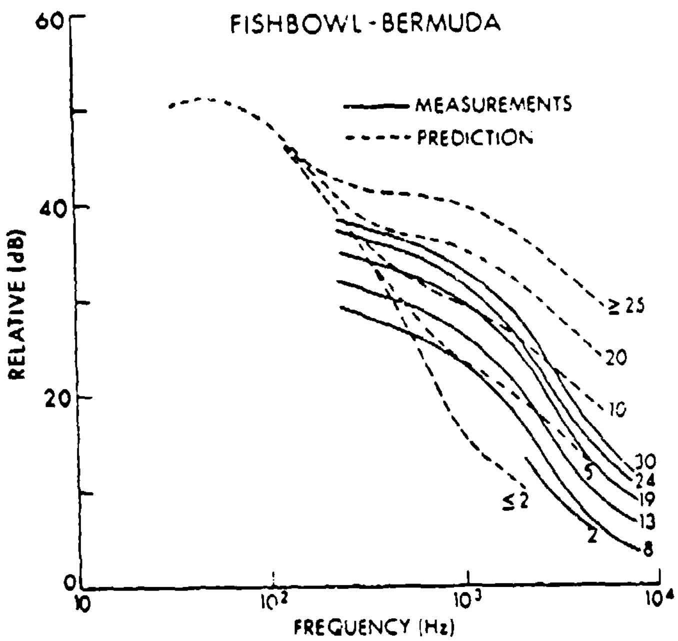


Also compared were the mean levels measured in the Southern Norwegian Sea by Walkinshaw and Vidale. This shows Vidale's predictions and the measured mean for a four-year period. Above 300 Hz the levels differ by about 5 dB. Although further comparisons of this type should be made, these few indicate that we might expect predictions of mean levels to be accurate to ±5 dB 75 percent of the time. Further measurements, especially those similar to the one by Vidale for 100 Hz snould be made for all frequencies to bear out this estimate of their reliability.

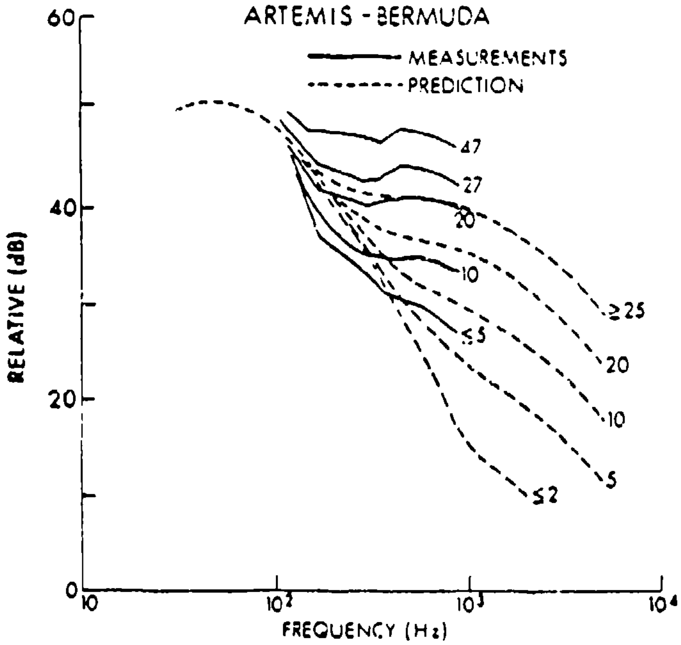


Of interest is the comparison of measured and predicted spectrum levels versus wind speed. Extensive ambient-noise measurements have been made with three arrays at Bermuda. The agreement with predicted levels was not good in any of them. As will be seen, the spectrum shape is different for each array and none agree well with the predictions. Also, for a given wind speed, differences of more than 20 dB between measurement and prediction are frequency seen.

This shows the predictions and measurements made with the TRIDENT Vertical Array of noise levels as a function of wind speed. Among other discrepancies, the 50-knot measured levels above 700 Hz are lower than the levels predicted for 25 knots.



Similarly, the 30-knot levels measured with the FISHBOWL array are lower than the levels predicted for 25 knots.



However, at the higher frequencies, the levels measured by ARTEMIS are higher than predicted for each wind-speed group.

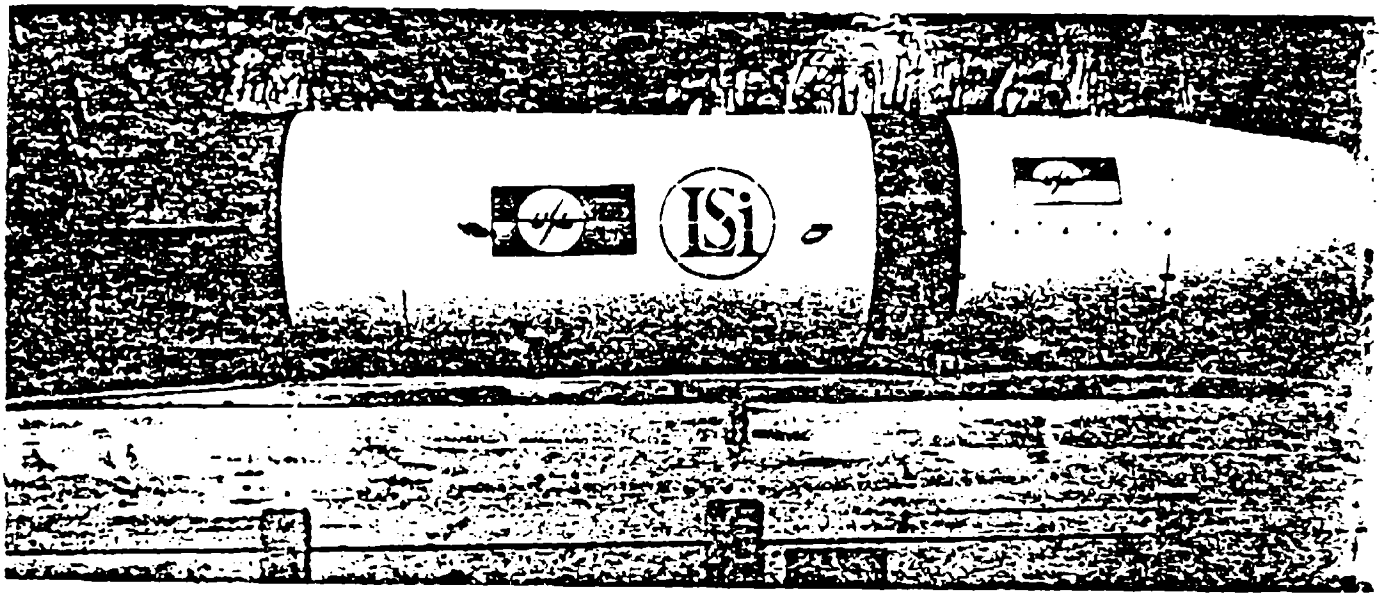
Thus, although the three surveys were in good agreement on ambient levels as a function of wind speed, the measured values do not agree among themselves or with other surveys. Clearly, the question of spectral slope and level as a function of wind speed is far from resolved. Part of the answer might be found in an understanding of depth dependence. The two arrays measuring relatively low levels were in deep water (over 10,000 ft). The array measuring relatively high levels was at the shallower depth of 6000 ft. Our limited knowledge of the depth dependence will be discussed later.

The key to improved predictions without any additional research may be a comparison such as Vidale made at 100 Hz. Similar comparisons can be made for more frequencies, as previously discussed. This, at least, would indicate how well we are progressing.

The following two types of additional studies, which would be continuations of the work that researchers are already doing, are needed:

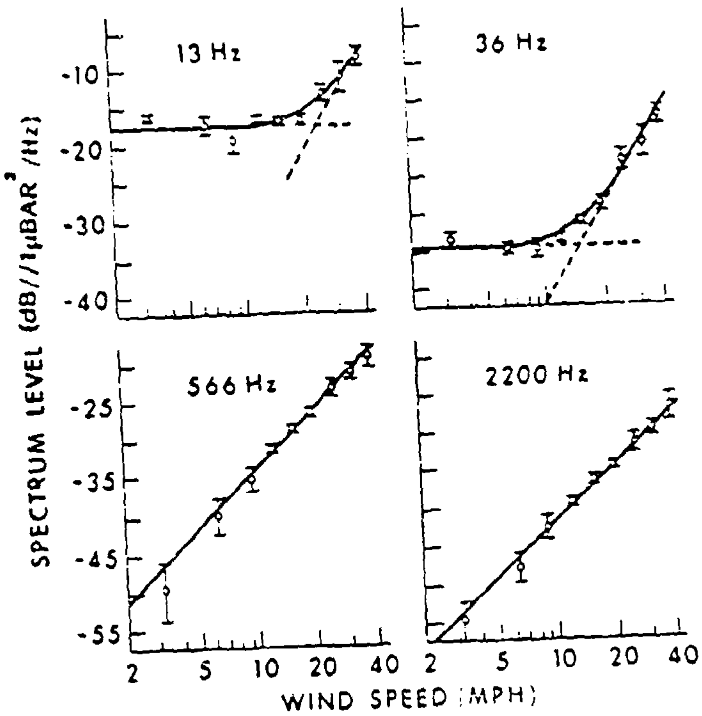
. More intensive studies should be carried out over long periods of time in the same area with the same equipment. Such studies are valuable for increasing our knowledge of the detailed characteristics of ambient noise. It is well recognized that because of the great variability of ambient noise, both in time and from one area to another, short-term measurements are of little use for making generalizations.

. The type of study exemplified in summary works, such as those by Wenz, A. D. Little, and Vidale, demonstrates the value of smaller quantities of data taken over wide geographical areas, and must also continue. In this regard, some standardization of methods, processing, requisite oceanographic data, etc., must receive attention so that we will be able to develop archival data bases for ambient noise in the same way the community has done with sound-velocity profiles, salinity measurements, and other oceanographic and bathymetric data.



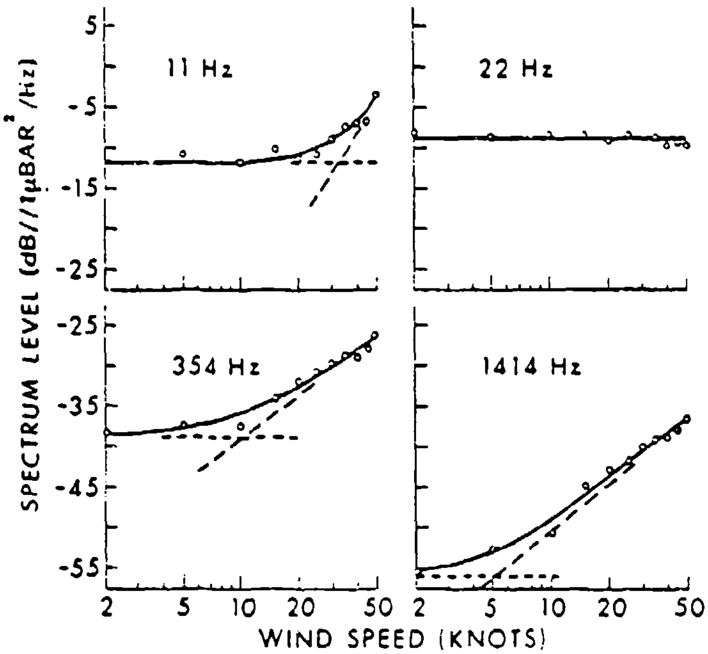
AUTOBUOY

A recent development in ambient-noise measurement (AUTOBUOY), originated at NUSC, permits an independent instrumented buoy to be programmed to dive to depths up to 20,000 ft and to record noise at various depths as it ascends. The buoy is 9 ft long and 21 in. in diameter. It was developed to decouple hydrophones making ambient-noise measurements from surface motion and to allow the research ship to move away from the measurement site so as not to contaminate the noise measurements. You will hear more about this system in a later presentation.

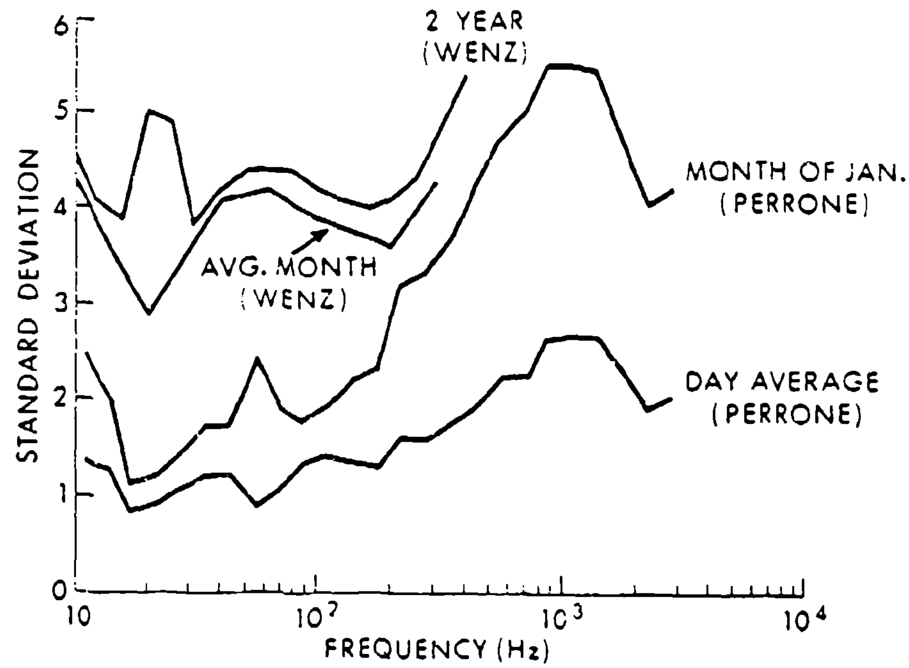


Now let us consider a few of the more important characteristics of ambient noise. The first is the dependence on wind speed.

Although there are many parameters that could be used to characterize the sea surface, wind speed has been found to be more highly correlated with ambient-noise level than with any other single parameter or combination of parameters. The relationship between wind-dependent ambient noise and wind speed is rather striking. Piggott studied the relationship in the very shallow water of the Scotian Shelf, where, also, there was very little noise from distant ship traffic. He found a linear dependence between the ambient-noise level and the logarithm of wind speed for all frequencies from 8 to 3000 Hz. As shown here, there was a non-wind-dependent portion of some frequencies, but in all cases the linear dependence was at the higher wind speeds.



Since a logarithmic scale is not normally used for such plots, we wondered if published data on deep-water ambient noise might also demonstrate such a linear relationship. Data based on measurements made over a range of depths from 2400 to 15,000 ft for frequencies from 11 to 2816 Hz near Bermuda were analyzed and found to demonstrate the linear dependence. This is a representative set of data. Wind dependence was found at about 11 Hz and above 100 Hz; there was no apparent dependence between 17 and 100 Hz. The results for 11 Hz are typical of the low-frequency wind dependence. The results for 22 Hz are typical of the non-wind-dependent region; 354 and 1414 Hz show the linear dependence found at higher frequencies.

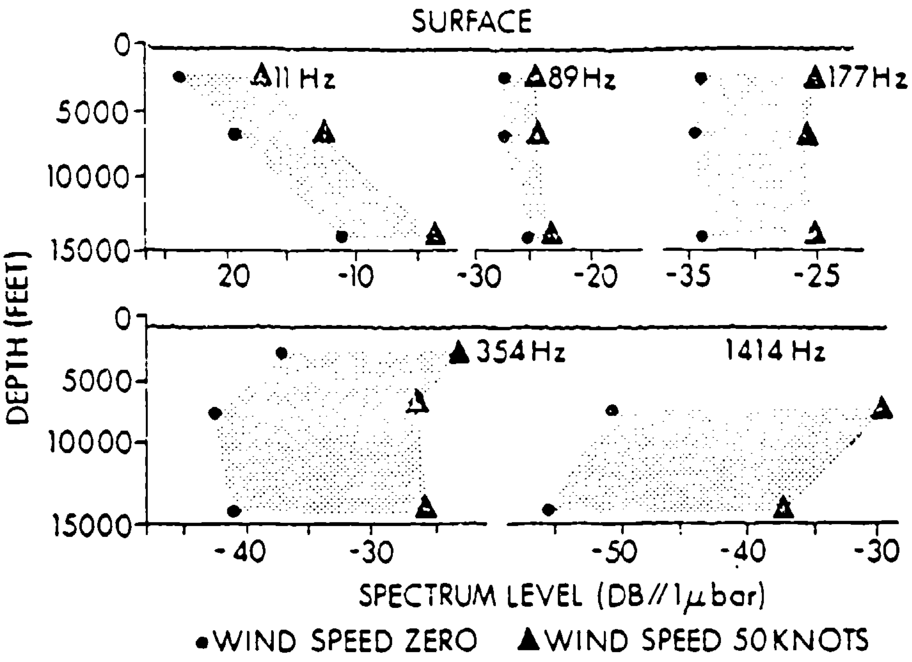


When the current ability to predict mean levels was discussed, it was also stated that knowledge of the variation about the mean was also important. Operational analyses based on mean levels alone are of limited value and can be misleading. For instance, there is considerable difference between a variation of ± 2 dB and ± 10 dB for most operational situations.

There is very little in the literature on this subject and, therefore, systems people need to be educated to use what is available. Wenz studied the variation using data from bottomed hydrophones on the west coast of North America for each month of the year and for the entire two-year period. To supplement these data, we analyzed Perrone's data for the month of January and studied the variations for a one-day period and for the entire month. This shows the standard deviation of the variation for periods of 2 years, 1 month, and 1 day. As would be expected, the variation is greater for longer periods. The difference between the average month and the month of January can probably be explained by weather and propagation conditions that differ from the average during January.

Except for the very thorough study by Wenz, available data are too sparse to enable anticipating what variations to expect. The results shown here do provide a place to start, but more data must be analyzed for this purpose.

It is important in making these comparisons that time periods be used corresponding to those of interest in systems analysis and performance prediction. Time periods spanning from a few seconds to a year have interest and meaning in such studies.



At least two studies are available on ambient noise as a function of depth. It is especially important to know more about this aspect as deep-submergence vehicles with sonars become a possibility and as deep-mounted arrays are employed in open ocean areas.

Perrone studied ambient noise at four depths, from 2400 to 15,000 ft, for frequencies from 11 to 1414 Hz. The results can be summarized by looking at the three frequency bands shown here. From 11 to 89 Hz, the levels were lower near the surface. At 11 Hz, the noise at 2400 ft was about 12 dB lower than the noise at 14,400 ft. This difference decreased to nearly zero at 89 Hz. In this frequency band wind speed did not affect depth dependence. As can be seen, the curves have the same slope for zero and 50-knot wind speeds.

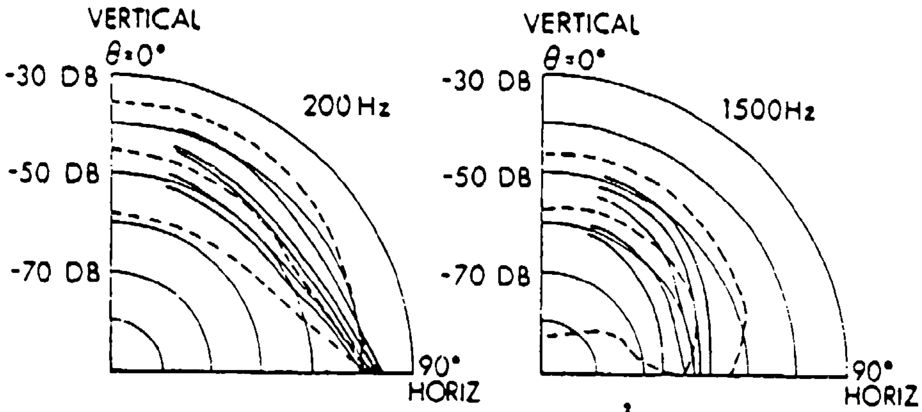
In the band from 89 to 177 Hz, there was essentially no difference in noise level between 2400 and 14,400 ft. Between 177 and 1414 Hz, the levels were higher near the surface. The level difference increased from zero to 4 dB for low wind speeds and from zero to 8 dB for high wind speeds. This can be seen best in the data for 1414 Hz. The difference at 50 knots is noticeably greater than at zero knots. In general, the level difference for the highest band is greater at higher frequencies and higher wind speeds. Also, a hydrophone at a depth of 15,000 ft showed significantly different levels when the primary source was distant shipping, although that hydrophone was only 600 ft below the one above. This, most likely, was caused by shipping, although that hydrophone was only 600 ft below the one above. This most likely, was caused by propagation conditions, the lower hydrophone bearing on the ocean floor and, thus, beyond the direct-path field. You will hear more on this subject in a subsequent paper.

Lomask and Frassetto, using the bathyscaph TRIESTE, made a series of experiments in the Tyrrhenian Sea where the shipping noise levels are low. They show wind-speed dependence over the frequency range of 10 to 240 Hz; however, no wind dependence is observed in Perrone's study. Consequently, it appears that the ambient noise spectrum levels do vary as a function of water depth, and they are dependent on the area and the balance between agitation and distant shipping.

We also know that noise levels in the SOFAR channel are frequently high because of the favorable propagation conditions from distant sources. Further study of depth dependence should include quantitative descriptions of the effect of the channel and of the other parameters that influence depth dependence.

Since a significant portion of ambient noise is generated by distant shipping, propagation conditions influence the ambient-noise level. However, the influence on system performance is not simply that of a higher background level. For instance, if we are listening to distant targets, and propagation conditions improve, the signal level, as well as the background level, will increase.

Undoubtedly a long-term program will be needed to cover a variety of propagation conditions and to average out normal fluctuations in the contribution from distant ship traffic.



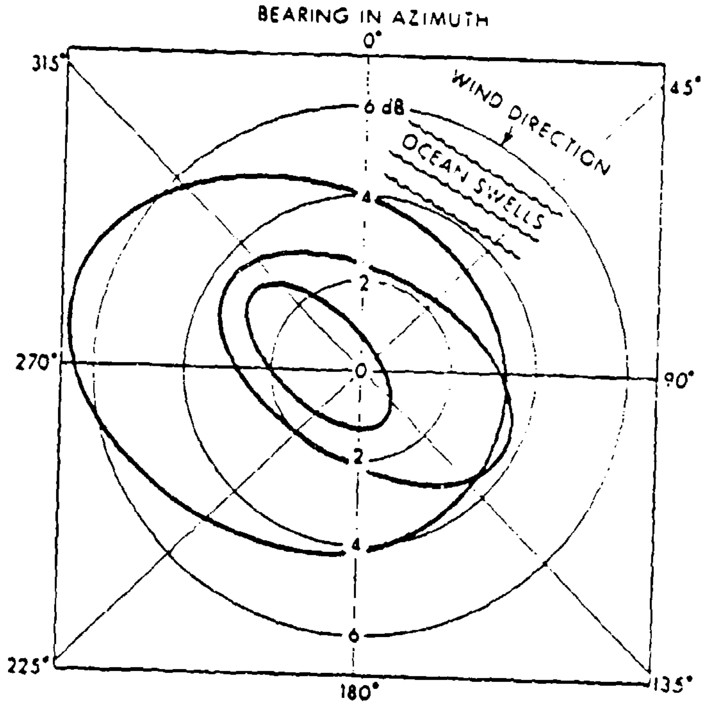
SPECTRUM LEVEL (dB//1μBAR^2/Hz/STERADIAN)

VON WINKLE ———
FOX - - - - - - - -

Fox and Von Winkle studied the vertical directionality of ambient noise in deep water. Both studies were conducted with the TRIDENT Vertical Array near Bermuda in 10,000 ft of water. Frequencies from 100 to 2800 Hz were studied. The dates of the experiments overlapped: Fox's measurements were made during the winter months, and those by Von Winkle were made during the winter and summer months.

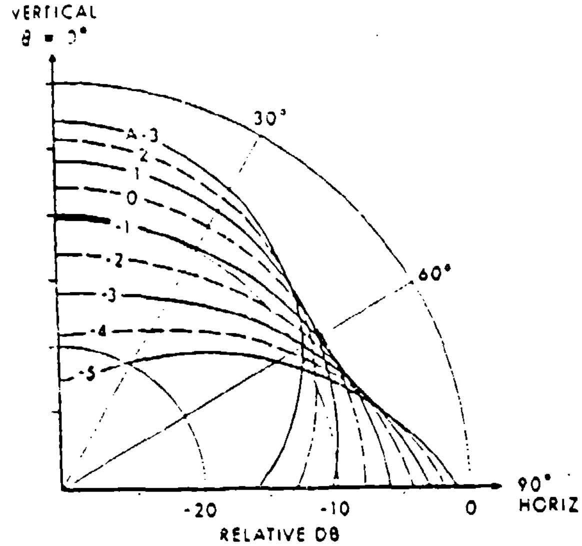
For the most part these results agree and support the contention that there are two primary sources. Each curve represents a wind-speed group, with the lower curves corresponding to the lower wind-speed groups. At the lower frequency of 200 Hz, relatively more noise arrives from the horizontal, whereas, at the higher frequency of 1500 Hz, relatively more noise arrives from the vertical.

The greatest difference between the two studies is that Fox's curves for low wind speeds show a relatively larger amount of horizontal noise. A probable explanation may be found in the analytical and experimental procedures and in one's definition of distant shipping. However, further work needs to be done to extend the frequency range to determine the directionality in shallow water. Another specific requirement is data for submarine operating depths of 400 to 600 ft.

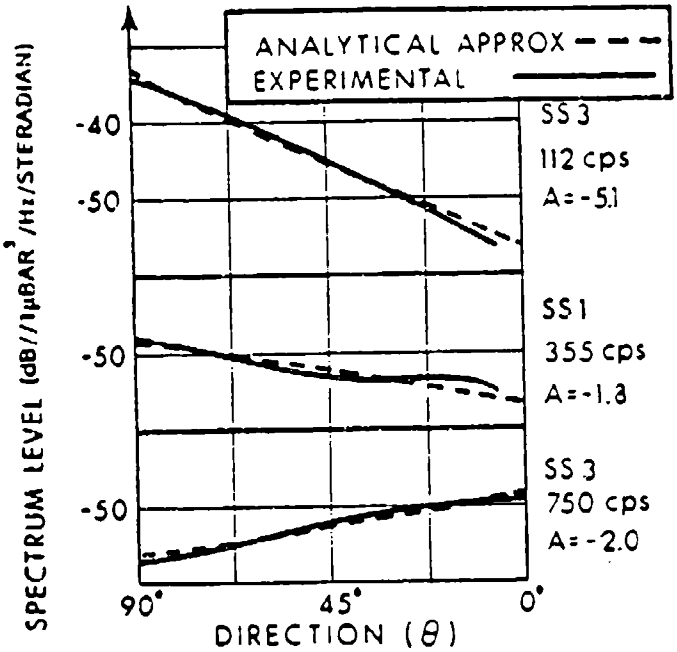


Becken has reported on studies of an array suspended near the surface and found an azimuthal dependence in the frequency band from 750 to 1500 Hz, as shown here. The maximum levels are consistently aligned with the wavefronts, and the minimum levels are consistently perpendicular to the wavefronts. The three curves are for different vertical angles, where zero degrees is "looking" straight up at the surface. The effect is more pronounced for larger angles.

Horizontal directivity is very important in evaluating null steering and adaptive beam-forming devices. More data are required to determine to what extent the promise of useful results for these sophisticated processing systems is valid. Priority for this work is probably the highest of all the noise studies.



The vertical directionality studies have provided an opportunity to check some theoretical models. Liggett and Jacobson, for example, have proposed a simple directivity function that compares favorably with some of the directionality results. The functions are shown in here for several directivity parameter values.



These are comparisons between the analytical approximation for various values of A (the directivity parameter value) and the experimental results. Some theoretical models, like this one, give promising results.

We have discussed various aspects of the background noise of the ocean. The features of this background are clearly of importance to system designers and yet after years of study there still exists a serious lack of data for all geographic and weather conditions. There are whole oceans where the data base is essentially nil. As one demands higher performance of underwater listening system, the demand for understanding of the peculiarities and subtleties of the medium increase.

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